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Tire Pressure Monitoring Device and Method of Monitoring Tire Pressure

The present invention relates to a tire pressure monitoring device and a method of monitoring tire pressure according to the preambles of claims 1 and 8. The invention further relates to a computer program product according to claim 12.

It is of great significance for vehicle safety to reliably monitor the tire pressure on all wheels of a motor vehicle. There are different approaches how to realize tire pressure monitoring systems. So-called tire pressure monitoring systems with direct pressure measurement, as described in application DE 199 26 616 C2, exist which determine the respective pressure in the associated wheel by means of pressure sensors in the individual tires. Systems of this type monitor the tire pressure on all wheels independently, yet they are relatively expensive as they require additional devices, e.g. for transmitting and evaluating pressure sensor information. Further, so-called indirectly measuring tire pressure monitoring systems are known, e.g. from DE 100 58 140 A1, which can detect pressure loss based on auxiliary quantities, e.g. by comparing the rolling circumferences of the individual wheels.

These systems suffer from the disadvantage that a defective tire will only be detected at a significant pressure loss. Admittedly, systems of this type are inexpensive and reliable,

yet they function only if pressure loss occurs on one wheel. If pressure loss occurs on several wheels at the same time, this condition will not be detected.

DE 100 60 392 A1 discloses a tire pressure monitoring device which comprises a combination of a tire pressure monitoring system with indirect measurement and a tire pressure monitoring system with direct measurement. The task of the tire pressure monitoring device described in this publication is to monitor inflation pressure loss on all four wheels by the combination of a tire pressure sensor and a tire pressure monitoring system with indirect measurement.

It is disadvantageous in this respect that when using only one tire pressure sensor, the wheels on which no tire pressure sensors are mounted can only be monitored with relatively high detection thresholds. The consequence is that inflation pressure loss is detected at a very late point of time only. It is achieved by the alternative use of two tire pressure sensors as mentioned in the above publication, with exactly one tire pressure sensor being arranged on each vehicle axle, that individual tire pressure nominal values can be determined for each axle. However, this provision does not lead to a considerably earlier detection of inflation pressure loss. As a tire pressure monitoring system with indirect measurement operates on the basis of rotational wheel speeds and, hence, is directly dependent on the wheel rolling circumference, pressure loss on the driven wheels can frequently be detected only very insufficiently or in rare moments of their free rolling.

When using a tire pressure sensor on only one wheel of the driven axle, it is only possible to detect very great pressure

losses on the other driven wheel. Besides, there is still the problem that wheel slip on a driven wheel can be interpreted as pressure loss on this wheel by the tire pressure monitoring system with indirect measurement because the tire pressure monitoring system with indirect measurement does not identify whether the wheel speed increase is due to a defective tire or a slip situation. For reasons of rigidity, it is therefore possible in a tire pressure monitoring system of this type to use only high detection thresholds for pressure loss detection.

In view of the above, an object of the invention is to provide a tire pressure monitoring device and a method of monitoring the tire pressure for safely detecting, in a reliable and low-cost fashion, pressure loss on several or all tires of a motor vehicle at an early time, in consideration of the wheel slip and at a high rate of accuracy.

This object is achieved by a tire pressure monitoring device according to claim 1 and a method of monitoring the tire pressure according to claim 8.

It is preferred that in a vehicle with several driven vehicle axles, the tire pressure monitoring system with direct measurement is arranged on the vehicle axle to which the maximum driving torque of the vehicle engine is applied. As a result, pressure loss on the driven axle is also detected when the driven wheels are exposed to driving torque or wheel slip, respectively, e.g. when the vehicle is accelerating. The non-driven wheels can be monitored safely by a tire pressure monitoring system with indirect measurement because the driving torque prevails on the driven axle only.

It is furthermore preferred that the wireless transmission of the tire pressure values takes place by radio transmission by means of a radio transmitter and radio receiver or by way of an optical transmission by means of transmitting diode and receiving diode. It is also preferred that there is an on-wire transmission link for transmitting the tire pressure values between the radio receiver or the receiving diode, respectively, and the evaluating unit.

The central reception antenna is preferably arranged on the vehicle in such a manner that the individual transmitter devices are allocated to the respective vehicle wheels by way of the field strength or the intensity of the transmitted signal, respectively.

In a preferred embodiment of the tire pressure monitoring device of the invention, the tire pressure monitoring system with indirect measurement, in addition to the wheel speed sensors on the non-driven vehicle axle, includes another wheel speed sensor on the driven vehicle axle or on a wheel of the driven axle. All vehicle wheels include wheel speed sensors in a particularly preferred embodiment.

In another preferred embodiment, an additional tire pressure measuring device is arranged on the non-driven vehicle axle or, in the case of all-wheel driven vehicles, on another driven vehicle axle.

It is preferred to connect a driving dynamics sensor furnishing information about the yaw rate and/or the lateral acceleration of the vehicle, to the evaluating unit in addition to the tire pressure monitoring system with indirect or direct measurement, with the result that cornering

maneuvers are detected safely and quickly. This leads to a more precise and faster pressure loss detection in the tire pressure monitoring system with indirect measurement.

The learning mode is preferably started by the actuation of a reset button, e.g. in the event of changing of tires. The reset button is actuated by the operator or a mechanic.

The invention further relates to a computer program product which comprises the method of the invention.

Further features of the invention can be taken from the sub claims and the subsequent description by way of five embodiments.

The tire pressure monitoring device of the invention provides two tire pressure sensors, one per wheel, on the driven axle in a first embodiment. The non-driven axle is monitored by way of wheel speed sensors already provided e.g. in a vehicle equipped with an anti-lock system (ABS). This arrangement is advantageous because pressure loss on a driven wheel is safely detected. Due to driving of a wheel (e.g. during acceleration of the vehicle) the effect utilized in the tire pressure monitoring system with indirect measurement is frequently so insignificant that pressure loss can only be detected safely by a tire pressure monitoring system with direct measurement. In the non-driven axle, however, a tire pressure monitoring system with indirect measurement is appropriate to safely detect tire pressure loss. Each tire pressure sensor has a transmitting unit and a receiving unit fitted to the vehicle to supply information about the pressure value of the tire to an evaluating unit. This renders position detection possible, i.e. the allocation of the individual wheels to their

installation positions (left front wheel, right front wheel, etc.). The influence of different coefficients of friction μ between tires and roadway has an effect on the driving wheels only because a rotational speed difference exists between a wheel at a high coefficient of friction μ_{high} and a wheel at a low coefficient of friction μ_{low} due to the torque applied to a driving wheel. Therefore, the tire pressure monitoring device described herein is able to safely and quickly detect an insignificant pressure loss even under so-called μ-split conditions (the wheels of the driven axle adopt different coefficients of friction). Different coefficients of friction may e.g. imply a high coefficient of friction μ_{high} on dry asphalt and a low coefficient of friction μ_{low} on an icy roadway. The non-driven wheels, however, do not depend on the coefficients of friction in terms of their rotational behavior. The result is that even insignificant tire pressure losses are safely and quickly detected by means of relatively low detection thresholds, in contrast to the relatively high detection thresholds in a conventional indirect tire pressure monitoring system according to the state of the art.

In contrast to the first embodiment, a central receiving unit for all transmitting units of the tire pressure sensors is used in a second embodiment. Position detection is also enabled thereby when the receiving unit is arranged in such a fashion, e.g. by being positioned more closely to a transmitting unit, that the wheels are allocated to their installation positions by way of the different field intensities of the transmitting units.

In a third embodiment, another wheel speed sensor is additionally used on the driving axle on a wheel of the driven axle or directly on the driven axle e.g. on the differential.

This provision allows detecting a simultaneous pressure loss on both wheels of the non-driven axle, or a simultaneous pressure loss on all wheels. Position detection is herein possible as well by using the arrangement of the receiving unit(s) as described in the first and second embodiments.

In a fourth embodiment, the first embodiment described is supplemented to such effect that wheel speed sensors are employed on all wheels. Likewise in this embodiment, position detection is possible by using the arrangement of the receiving unit(s) described in the first and second embodiments. Further, this embodiment is favorable in that a fallback level detecting pressure loss on the individual tires exists due to the tire pressure monitoring system with indirect measurement even upon failure of the tire pressure monitoring system with direct measurement.

In a fifth embodiment, a tire pressure sensor is employed on a wheel on the non-driven axle in addition to the first embodiment. This provision allows detecting pressure loss more quickly.

The employment of driving dynamics sensors such as yaw rate sensor or lateral acceleration sensor allows further improving the above-mentioned embodiments because e.g. a cornering maneuver is safely detected by the driving dynamics sensors so that the monitoring times of the tire pressure monitoring system with indirect measurement are shortened.

The methods of monitoring the tire pressure are explained in the following by way of the above-mentioned embodiments. As a starting point, a vehicle with a driven front axle is examined, while the method of the invention is not limited to

vehicles with a driven front axle. The wheels VL (left front) and VR (right front) are directly monitored by wheel pressure sensors. The wheels HL (left rear) and HR (right rear) are monitored by wheel speed sensors. The wheels HR (left rear) and HR (right rear) are monitored by wheel speed sensors. The wheel speed sensors measure the wheel speeds of the individual wheels HL and HR, the said wheel speeds being composed of the wheel rolling circumferences and the wheel revolution times T for a wheel rotation. Each wheel HL and HR has an individual wheel revolution time (T_{HL}, T_{HR}).

According to the first embodiment, the tire pressure monitoring system with indirect measurement, after actuation of a reset button, learns a reference value $X1_{ref}$ on the basis of the two wheel speed sensors on the non-driven axle. This reference value $X1_{ref}$ is mainly based on a difference between the two wheel revolution times T_{HL} and T_{HR} of the wheels HL and HR under review, and the difference is divided by the sum of the two wheel revolution times T_{HL} and T_{HR}. The reference value $X1_{ref}$ is determined in consideration of difference vehicle speeds and in consideration of cornering maneuvers. After completion of this learning phase, a current comparison value $X1_{current}$ is constantly determined from the same wheel revolution times T_{HL} and T_{HR} according to the method described hereinabove. A difference is produced from the comparison value $X1_{current}$ and the reference value $X1_{ref}$. This difference is compared with a threshold value S previously determined from the reference value $X1_{ref}$ or a threshold value -S, respectively. When this difference exceeds the threshold value S, or is lower than the threshold value -S, respectively, pressure loss on one of the wheels HL and HR can be precisely allocated to the respective wheel HL or HR. In this respect, it is important that the difference between the comparison value $X1_{current}$ and the

reference value $X1_{ref}$ is produced only in the same driving situation, e.g. at the same vehicle speed and when straight travel is detected. In vehicles equipped with an electronic stability program (ESP), it is easily possible to evaluate the data of a yaw rate sensor or lateral acceleration sensor to procure information about a cornering maneuver.

According to the third embodiment, the tire pressure monitoring system with indirect measurement learns different reference values $X1_{ref}$ and $X2_{ref}$ by way of an additional wheel speed sensor, e.g. on the wheel VL of the driven axle. The reference value $X1_{ref}$ is determined like in the previous embodiment. The reference value $X2_{ref}$ is basically composed of the difference between the two wheel revolution times T_{HL} and T_{VL}, with the difference being divided by the sum of the wheel revolution times T_{HL} and T_{VL}. The reference value $X2_{ref}$ is learnt in different driving situations like the reference value $X1_{ref}$. It does not matter in this arrangement, on which wheel of the driven axle the additional wheel speed sensor is arranged. The wheel speed sensor can also be arranged on the differential of the driven axle. The wheel speed sensor can also be arranged on the differential of the driven axle. This additional wheel speed sensor allows detecting stealthy pressure loss on the non-driven axle. Monitoring the non-driven axle takes place similar to the first embodiment. Only if a tire pressure sensor detects a pressure difference on the driven axle will a current comparison value $X2_{current}$ be produced corresponding to the reference value $X2_{ref}$ in consideration of the same driving situations. A difference between the current comparison value $X2_{current}$ and the reference value $X2_{ref}$ is produced. This difference is compared to a previously defined threshold value S1. If this difference is lower than the threshold value S1,

there is a stealthy pressure loss on both wheels of the non-driven axle.

A complete indirect tire pressure monitoring system as described hereinabove prevails according to the fourth embodiment. This increases the fail-safety of the system further because a system according to one of the above-mentioned embodiments prevails upon failure of one or more of the wheel speed sensors. The non-driven axle is monitored in this arrangement like in the first embodiment. The driven axle is monitored similar to the non-driven axle. Stealthy pressure loss on a vehicle axle can be detected in addition by the method described in the third embodiment.

The other embodiments are not described in detail herein because the additional use of a tire pressure sensor with direct measurement achieves an obvious improvement in accuracy as the tire pressure value is directly provided. The mentioned embodiments are considerably improved in terms of shorter monitoring times or cornering detection by the additional use of further driving dynamics sensors, as has been described hereinabove.